ERCANBRACK

The Design of the Motive Power Equipment for an Electric Street-Car

Railway Electrical Engineering

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THE DESIGN OF THE MOTIVE POWER EQUIPMENT FOR AN ELECTRIC STREET-CAR

BY

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IN THE

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June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

HAL EDMUND ERCANBRACK

ENTITLED THE DESIGN OF THE MOTIVE POWER EQUIPMENT FOR AN ELECTRIC STREET-CAR

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Railway Electrical Engineering

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I N D E X

THE DESIGN OF THE MOTIVE POWER EQUIPMENT FOR AN ELECTRIC STREET-CAR

Introduction.

In the operation of city railway cars, an average of about nine-tenths of the power consumption is used in their acceleration. That is, in acceleration, the energy curve rises to an excessive height immediately at the start of the car and gradually becomes lower until it forms a straight line when the speed of the car is uniform.

From a study of curves of this kind, it is seen that a cutting off of the upper parts of the curves during acceleration would result in a great saving in the current consumption and cost of plant installation and operation.

In bringing the car to rest, energy is dissipated at the brake shoes and nothing is realized from this wasted energy.

By designing a machine which would utilize this energy which is ordinarily wasted in bringing the car to rest and give it forth again in accelerating the car, we have a means of eliminating the excessive consumption due to acceleration.

Principle of Design

The main feature of this thesis, therefore, is the design of a reversible air machine, i.e., one which can be operated as a compressor in one case and which can also be changed to operate as a compressed air engine in the other case, by a system of cams and connections. This system, of course, necessitates a reservoir for holding the com-

pressed air.

The ordinary electrical equipment will be installed on the car with the exception that two motors will be used instead of four as on the larger city cars at present, or if the system should be installed on the smaller two truck cars, where two motors are ordinarily used, two motors will be used but of smaller capacity. Considering single truck cars, one electric motor will be used and one air machine; and one the double truck cars, one motor and one air machine will be placed on each truck. This thesis, however, will be confined to the large "Pay as you Enter" type of car such as are used in Chicago at present.

The tractive power of electric cars used in the United States usually runs from 20 to 25 percent of the weight on the car wheels. Considering this, the first part of this design will be to select the body and trucks of the car which will have a known weight, from which can be calculated the maximum allowable tractive power.

From the formula

$$L \times 250 \times \frac{\pi d^2}{4} \times 8 = T \pi D$$

where L = length of compression stroke in feet,

250 = pounds gauge pressure used in the reservoir which is used in connection with the compression,

d = diameter of compressor cylinders in inches,

T = tractive power delivered to the rails,

D = Diameter of car wheels in feet,

and 8 = number of cylinders in the two air machines,

we arrive at

$$T = \frac{500\ L\ d^2}{D}$$

By subtracting the tractive power which the chosen motors will give from the total tractive power necessary to move the car under all conditions for rated speed and capacity, we obtain the tractive power which the air machines must give in accelerating the car. Having determined this, by substitution in the above formula, we are able to choose the size of the cylinders, the ratio of the stroke to the diameter depending, however, on the conditions as to space on the trucks. If a reduction gearing is used, the formula will read

$$T = \frac{500\ L\ d^2}{D} \times G \qquad \text{where } G = \text{gear ratio.}$$

Then with the size of the cylinders known and the average length for bringing the car to rest known or assumed, the size of the reservoir can be calculated which will bring the pressure up to that assumed at the beginning, 250 pounds per square inch. From text books, we know that when the temperature of a volume of gas remains constant, we have the relation

$$P\ V = P_1\ V_1$$

where P and V represent the pressures and volumes of the gas.

Or

$$V = \frac{P_1\ V_1}{P}$$

where V_1 = volume of all the air compressor cylinders for one stroke each. Then

$$V = \frac{V_1 \times 15}{265}$$

where 15 = the normal atmospheric pressure and

265 = the absolute pressure in the reservoir when the gauge reads a pressure of 250 pounds per square inch.

Then V times the number of strokes which the compressor pistons make while the car is being brought to rest, results in the volume of the reservoir, from which, its proportions can be assumed according to conditions.

Of course, if the average length for bringing the car to rest is not long enough to fill the reservoir at 250 pounds pressure which is sufficient to start the car for a desired distance, the air compressors may be connected while the car is being run by the motors and a larger reservoir used. Or if there is not sufficient tractive power developed by the engines, a higher gear ratio may be used when there is not room enough to make the cylinders larger.

The motors and air machines will be used together in the acceleration of the car and when it is well under way, the motors will be used alone and their size will depend upon the desired maximum speed of the car. The compressors will be put into use while the car is being brought to rest and pump air into the reservoir, thus utilizing the energy otherwise dissipated at the brake shoes.

Design

In starting the design according to the foregoing

principles, the following assumptions are made: The average weight on the wheels of the "Pay as you Enter" type of cars is 30 tons;- two-50 horse power motors will be used;- 250 pounds pressure in reservoir;- two air machines - 4 cylinders each will be used;- 33-inch car wheels;- 150 feet for bringing the car to rest.

Then considering 25% of the weight on the car wheels as the tractive power to be used on the car, we have,

25% of 60,000 = 15,000 pounds

allowable tractive power. Then allowing the compressed air engines to take care of half of the tractive power, we have

7500 pounds tractive power for the engines and

7500 pounds tractive power for the two electric motors,

the capacity of each motor being the same as on the original car.

In the formula
$$T = \frac{500\ L\ d^2}{D},$$

let T = 7500 and

D = 2.75 feet.

Then
$$7500 = \frac{500\ L\ d^2}{2.75}$$

and
$$L\ d^2 = 41.25\ .$$

Let L = 5/6 feet

and
$$d^2 = 49.5$$

d = 7 inches = diameter of cylinders.

Then taking 150 feet as the average distance for bringing the car to rest;

150 feet = 7200 inches.

A 33-inch wheel travels $33 \times \pi$ inches in one revolution.

Then

$$\frac{7200}{33 \times \pi} = 69.5 \text{ or } 70 \text{ revolutions in 150 feet of travel.}$$

Then with a gear ratio of 1 : 1, the piston strokes for a single acting engine are the same.

Considering the reservoir,

$$\dot{V} = \frac{V \times 15}{265}.$$

With 7" x 10" cylinders, $V_{,}$ = 384 cubic inches = volume of one cylinder.

$$V = \frac{384 \times 15}{265} = 21.8 \text{ cubic inches} \doteq \text{volume of}$$

the air under pressure of 250 pounds guage.

Then since there are eight cylinders in the two engines,

70 x 8 x 21.8 = 12150 cubic inches or 7 cubic feet which is the volume of the air compressed with the car traveling 150 feet. This, then, equals the size of the reservoir.

Due to the fact that only about 50 per cent efficiency can be realized from an engine of this sort, a gear ratio of 2 : 1 may be used with the same size of cylinders. Then the number of strokes would be 140 in bringing the car to rest and the capacity of the reservoir would be doubled also.

Now considering 25 miles per hour as the average maximum speed of city cars between stops, the strokes per min-

ute of the pistons would equal

$$\frac{12 \times 2300}{33 \times} = 255 \text{ strokes}$$

when a 1 : 1 gear ratio is used. But with a gear ratio of 2 : 1, this speed of strokes would be too high since about 300 strokes per minute is the most practical speed to operate engines of this sort.

Since the size of cylinders is about as large as can be conveniently put on trucks where four cylinders are used, a compromise may be arrived at,which will take care of this 50 per cent efficiency of the air machines by leaving the size of the reservoir as 14 cubic feet and the gear ratio as 1 : 1 without changing the size of the cylinders. This size of reservoir is better since with a small one of 7 cubic feet, after the first few strokes of the pistons, the pressure in the reservoir would be so reduced as to lower the power of the engines by more than half. This size of reservoir with the original size of cylinders as chosen, necessitates running the compressors for about 300 feet instead of 150 feet. This may be done while the motors are running without much more current consumption. In this manner, the pressure in the reservoir can be brought up to such a point that in bringing the car to rest in the remaining 150 feet as allowed, the final pressure will be brought up to 250 pounds. This can be done to a great degree of accuracy with but little practice.

Therefore,

Gear ratio 1 : 1 will be used,

7" x 10" cylinders will be used,
and 14 cubic feet reservoir.

In calculating the valve lift, 6000 feet per minute is used as the velocity of the air.
On this assumption,

$$\frac{\pi d^2}{4} \times L \times RPM = \frac{\pi 7^2}{4} \times 10 \times 255 =$$

98000 cubic inches per minute.

$$\frac{98000}{1728} = 57 \text{ cubic feet per minute} = \text{velocity of air}$$

through the cylinders.

$$\text{Then } \frac{57}{6000} = \frac{X \text{ (area of port)}}{38.5 \text{ (area of cylinder)}}$$

Then X = .36 square inches.

Assuming 1-1/2 inch poppet valves, from formula
area of opening = circumference x valve lift x .71,
we have .36 = 4.71 x X x .71 ,

$$X = \frac{.36}{3.35} = .108 \text{ inches or } 1/8 \text{ inch lift.}$$

Description

Plate 1 shows the cross-section view and head end view of the cylinders, Fig. 1 and 2, and also various views of the cylinder head, Fig. 3, 4, 5, 6 and 7, which contain the valve seats and air inlets and outlets.

Plate 2 shows three views of the piston, Fig. 1, 2 and 3, showing the general construction. The poppet valves

which are the type chosen are shown on this plate, Fig. 4 and 5.

Plate 3 shows the crank and connecting rod construction.

The figures on Plate 4 are partly drawn to scale and partly schematically. Figure 1 represents the cam rod and bevel gear arrangement. This shows the scheme used for changing the set of cams so that the machine will act as a compressor or as an engine. Figure 3 is a schematic diagram of the electrically operated air valve which admits air from the reservoir to the cylinder at the end of the cam rod. This air valve is the standard type of valve now used in electrically operated work. The air works against the spring as shown and forces the cam rod over so that another set of cams is brought against the poppet valve stems thus changing the action of the machine from that of a compressor to that of an engine. The spring shown in the figure holds the rod so that normally with no air pressure in this cam rod cylinder, the machine works as a compressor. A worm gear is used to transmit the crank action to the cam rod. This rod is a hollow tube, feather keyed to a smaller rod over which it slides in making the changes. The smaller rod receives power or motion from a set of bevel gears and the hollow rod carries the cams proper.

Fig. 2 represents the cam on the cam rod working against the poppet valve roller. This also shows the cam construction as well as the roller.

Plate 5 shows various outside views of the crank case

in which the axle supports can be seen.

Plate 6 shows the side elevation of one cylinder working and also a plan view of all cylinders and the respective positions of the pistons in the different cylinders. The cam rod supports and the rear beam support of the machine are also shown here.

Plate 7 shows the front view of the car truck and the air machine in position. This also gives a good idea as to the support on the car axle and the relative size of the machine and truck.

Plate 8 shows a top view of the machine in place on the truck. This view also shows the beam support to good advantage and the position of the air valve and cam rod cylinder. The electric motor is not shown but will be placed on the other car axle. The same system will be carried out in the other car truck.

Plate 9 shows a schematic view of the air system and the air control valve. Other views of the control are shown in figures 2, 3 and 4. Figure 2 represents the outside or bottom part of the control with the air pipe connection arrangements. Figure 3 represents the top which bolts to the one shown in figure 2 and holds the movable part in place. Figure 4 shows the movable part of the control which is operated by a handle the same as all controls. The circular recess cut in the side of this part is the connecting part between the different pipes so that the air can pass from the two adjacent pipes in that position of the control. Above this recess is shown a brush contact which closes the circuit

to the electrically operated air valve for the cam rod shifting operation. The two brushes shown in figure 5 which run to the air valve are fastened in the piece shown in figure 3 and set in such a position that when the control handle is in the air engine position, the circuit is closed and the cams are shifted.

Method of Operation.

In the schematic diagram are shown the various control positions.

First position is the one in which the air connections to the cylinders are closed and the pistons are working against the air as a cushion which forms a sort of final braking. This position of the control will not be used much since the volume of the air in the pipes will allow for too much elasticity. The car will also be equipped with the regular air brake system for the final braking of the car.

Second position is the neutral position in which the cylinders are open to the air and no work is being done on or by the air. This is the position in which the controller will normally be set for running between stops after the car is brought up to speed and before it is being brought to rest.

Third position is the one in which the machine is working as an air compressor with the cam rod in its normal position.

Fourth position is the one in which the machine is working as a compressed air engine with the air supply com-

ing from the reservoir and the contact made to close the circuit to the air valve for shifting the cam rod to the other position.

Suppose the car is at rest and the reservoir full of air at 250 pounds guage pressure. To start the car, the brakes are first released as usual. Then the air controller is switched from the 2d position to the 4th position which may or may not start the car in motion according to existing circumstances. Next, whether the car is in motion or not, the electric controller is turned and the motors brought into use. After the speed of the car has become uniform, the air controller is switched back to the 3d position and air is pumped into the reservoir until the pressure reaches a point at which it is known that the bringing of the car to rest in the stated 150 feet will bring it up to 350 pounds. When the pressure has reached this critical point as we will call it, the air controller is switched back to the 2d or neutral position and left there until within 150 feet from the next stop. The electric controller is shut off if not already in that position and the air controller is again switched over to the 3d position and left there until the final stop is made and then put back to neutral. The final stop is made by the air brake.

It is best to watch the reservoir guage during acceleration and always manage to keep it about 50 pounds so as to allow for sudden braking as the air brake system supply is taken from this reservoir.

A little practice in the operation of this car will enable one to do it with ease notwithstanding the extra control handle as compared with the ordinary electric car.

Plate I.

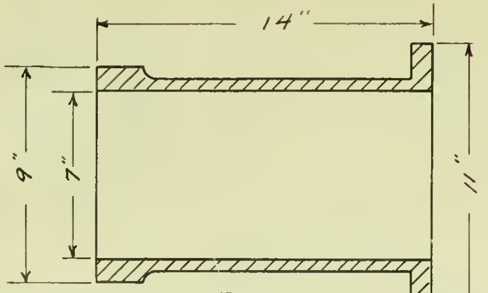

Fig. 1.

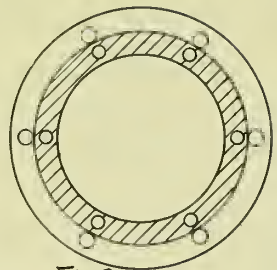

Fig. 2.

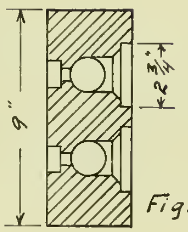

Fig. 3.

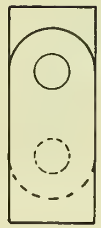

Fig. 4.

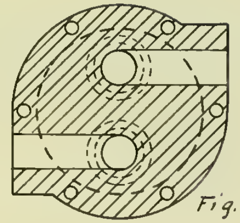

Fig. 5.

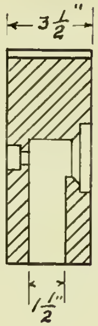

Fig. 6.

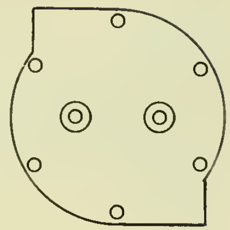

Fig. 7.

RY. ENG. DEPT.

UNIV. OF ILL.

THESIS DESIGN

DETAILS
of
CYLINDER AND HEAD
of
AIR MACHINE

Scale $\frac{1}{8}$" = 1" June 1-09

H.C. Excanbrack.

Plate II.

RY. ENG. DEPT.
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THESIS DESIGN

DETAILS
of
PISTON and POPPET VALVE
for
AIR MACHINE

Scale 3/16" = 1"
3/4" = 1"

June-1-09.
H.E. Ercanbrack.

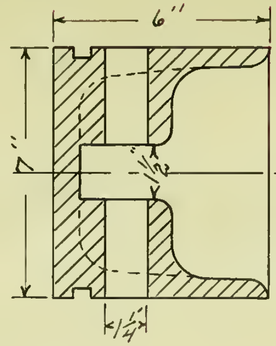


Fig. 1.

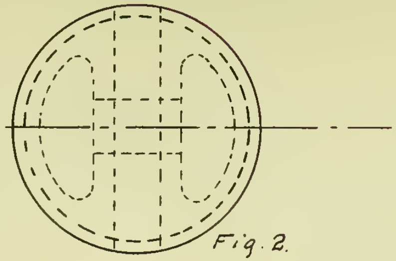


Fig. 2.

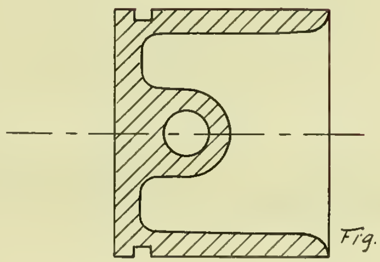


Fig. 3.

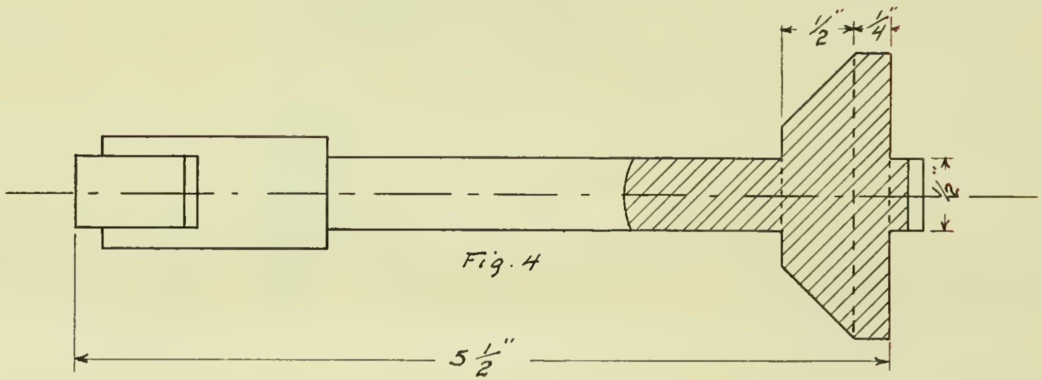


Fig. 4

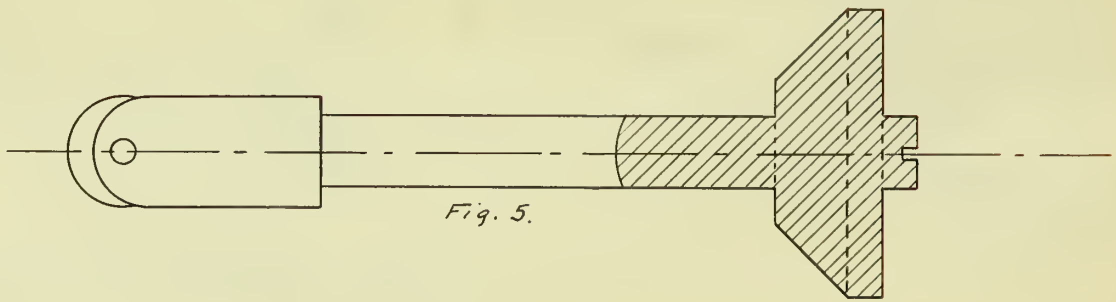
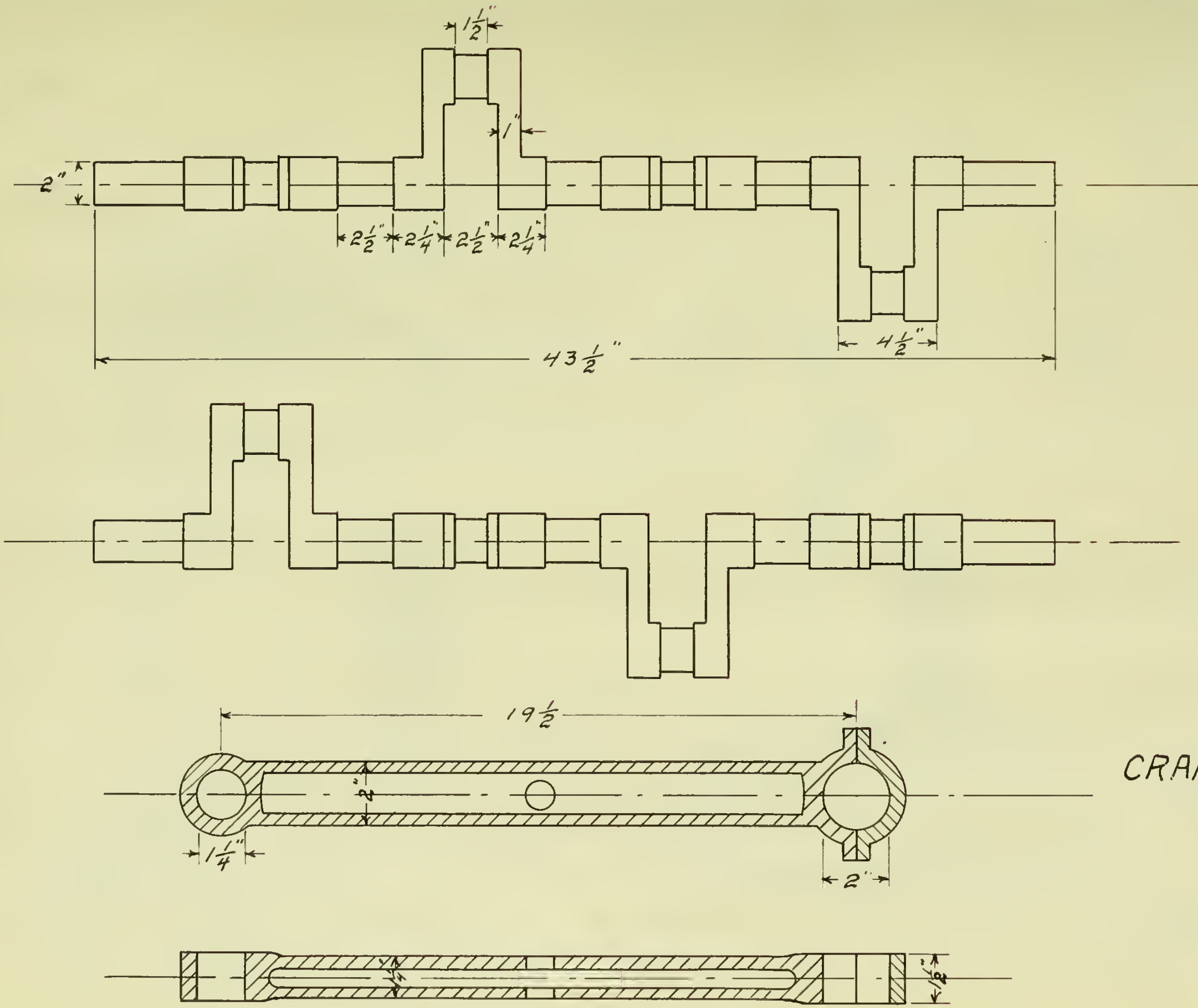


Fig. 5.

Plate III.



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THESIS DESIGN

DETAILS
of
CRANK and CONNECTING ROD
for
AIR MACHINE

Scale
1/8" = 1"
3/16" = 1"

June-1-09.

H.E. Ercanbrack.

Plate IV.

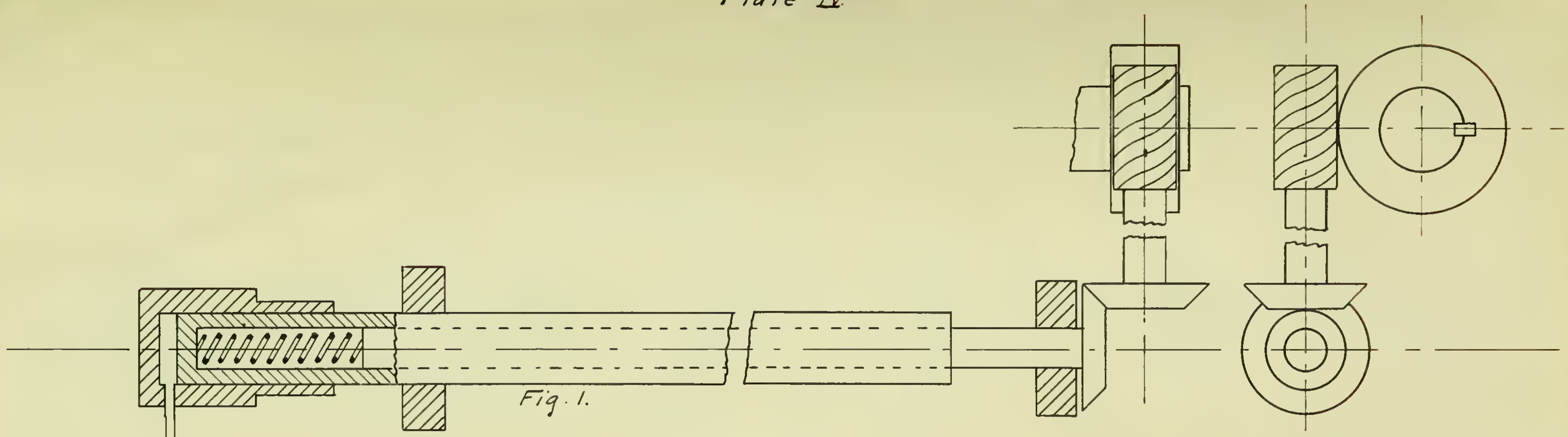

Fig. 1.

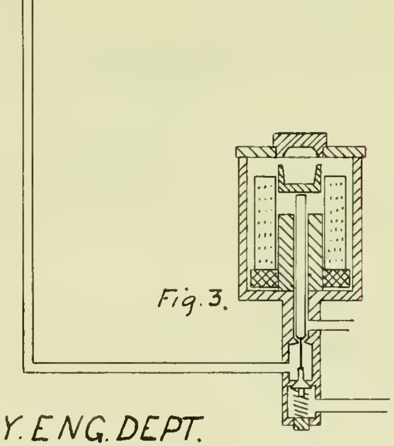

Fig. 3.

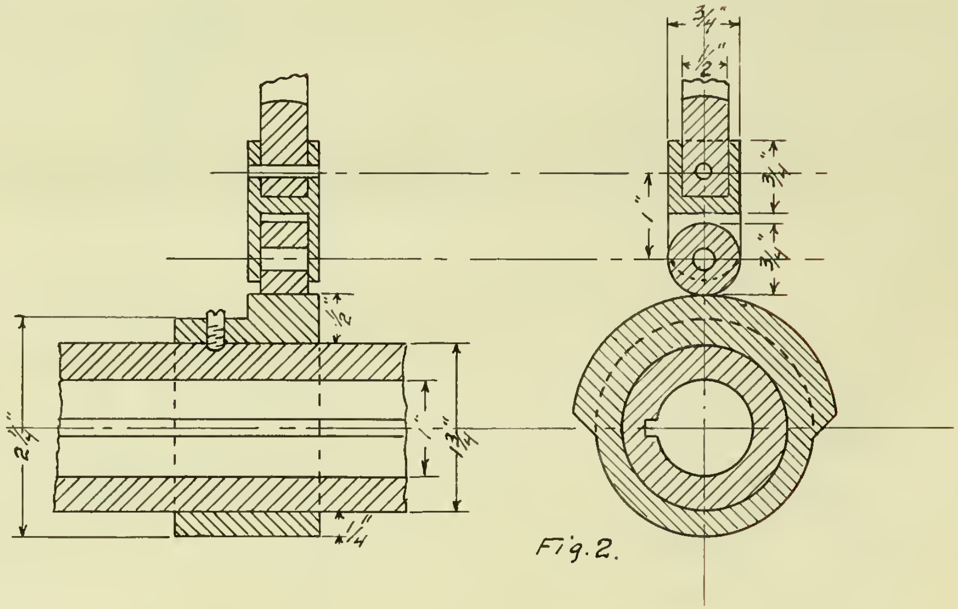

Fig. 2.

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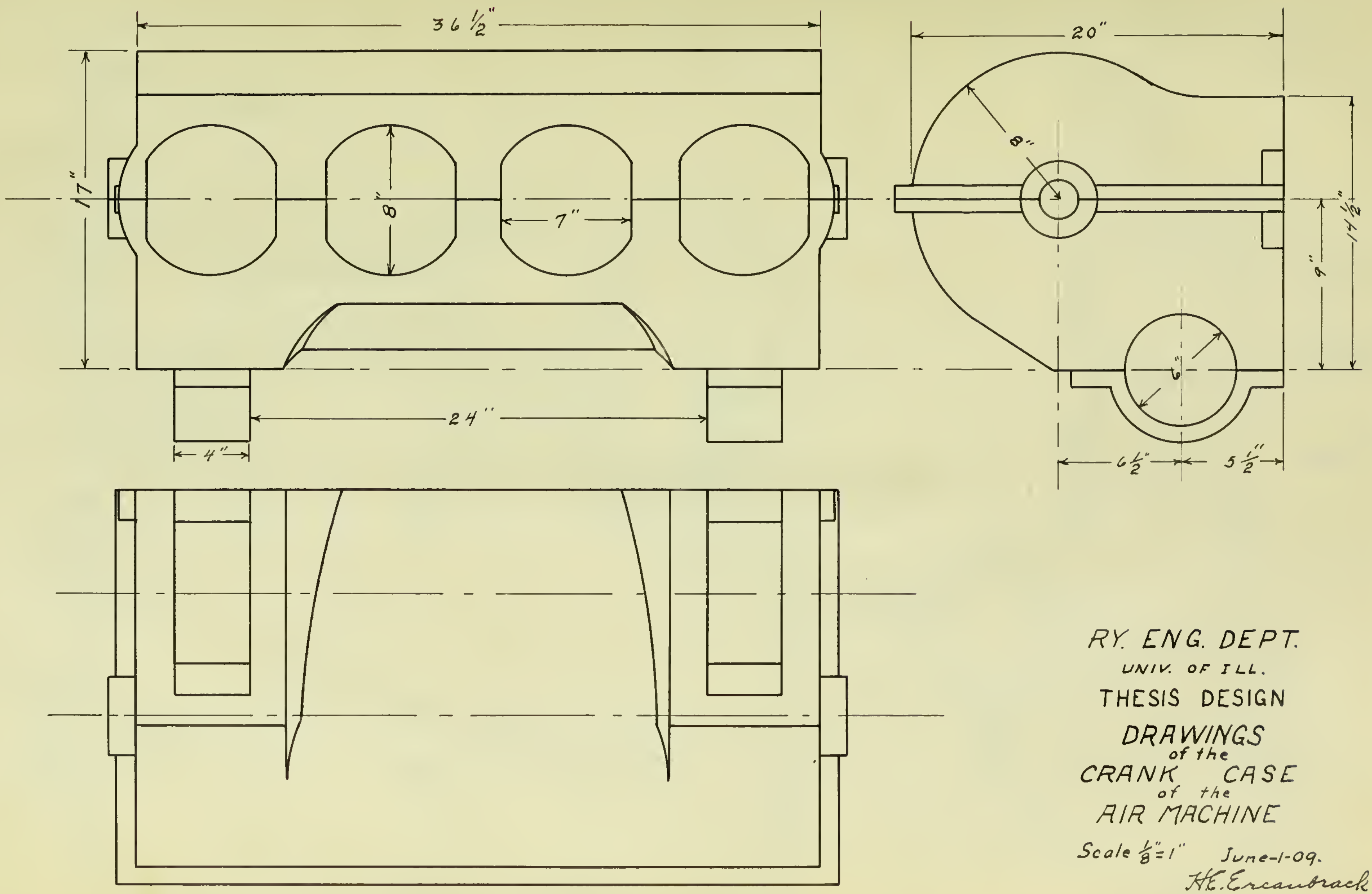
THESIS DESIGN

SCHEMATIC DIAGRAM
of the
CAM ROD and SHIFTING APPARATUS
and
DETAILS
of the
CAM and VALVE ROLLER
for
AIR MACHINE

Scale 1/2" = 1" June-1-09.

H. E. Encanbrack.

Plate V.



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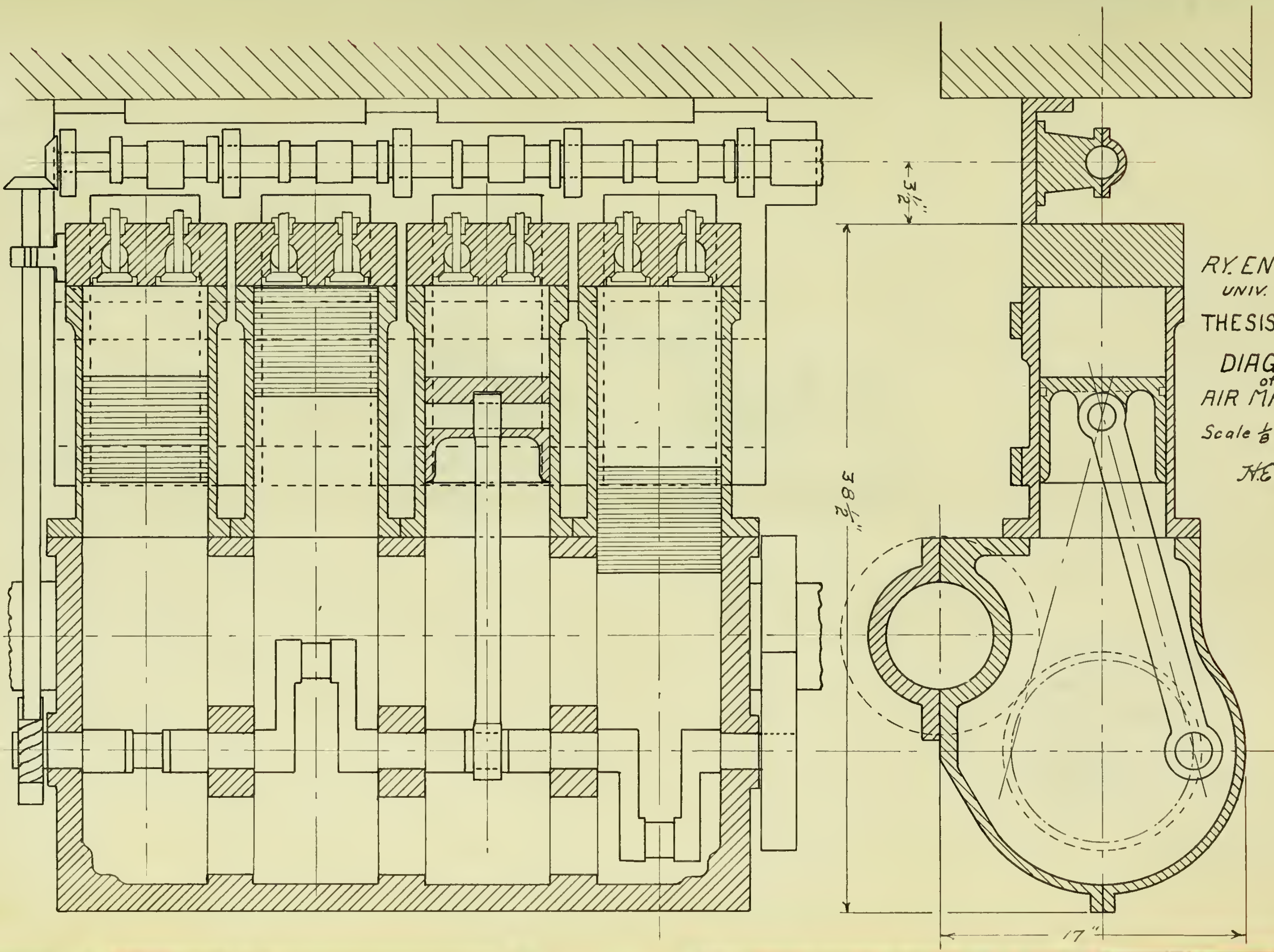
THESIS DESIGN
DRAWINGS
of the
CRANK CASE
of the
AIR MACHINE

Scale 1/8" = 1"   June-1-09.

H.E. Ercanbrack.

Plate VI.



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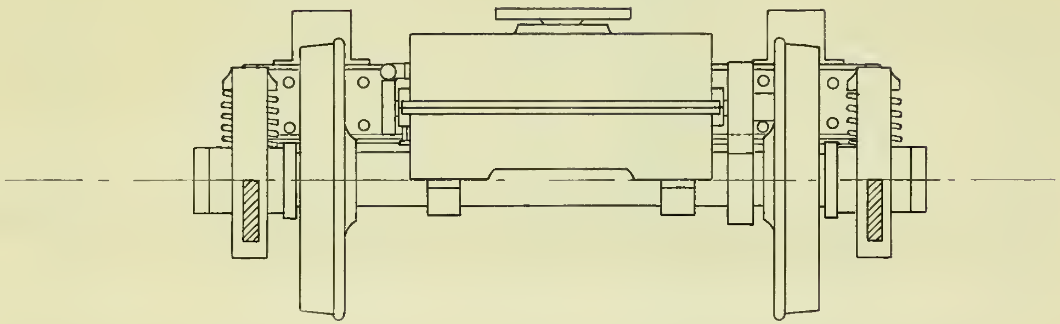
THESIS DESIGN
DIAGRAMS
of the
AIR MACHINE
Scale 1/8" = 1"
June-1-09
H.E. Ercanbrack

Plate VII.



RY. ENG. DEPT.
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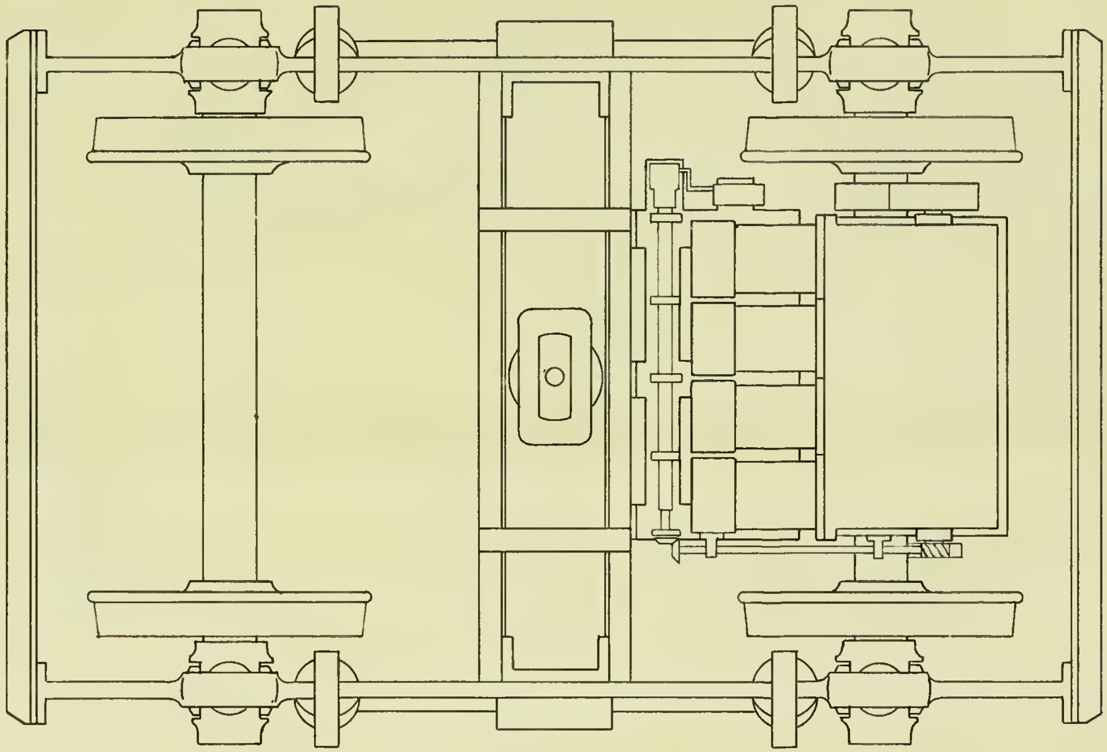
THESIS DESIGN
FRONT END VIEW
Showing
AIR MACHINE IN POSITION
on
CAR TRUCK
June-1-09 H.E. Ercanbrack.

Plate VIII.



RY. ENG. DEPT.
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THESIS DESIGN
PLAN VIEW
Showing
AIR MACHINE IN POSITION
on
CAR TRUCK
June-1-09.
H.E. Ercanbrack.

Plate IX.

RY. ENG. DEPT.
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THESIS DESIGN
SCHEMATIC DIAGRAM
of the
AIR SYSTEM
and
AIR CONTROL
June-1-09.
H.E. Ercanbrack

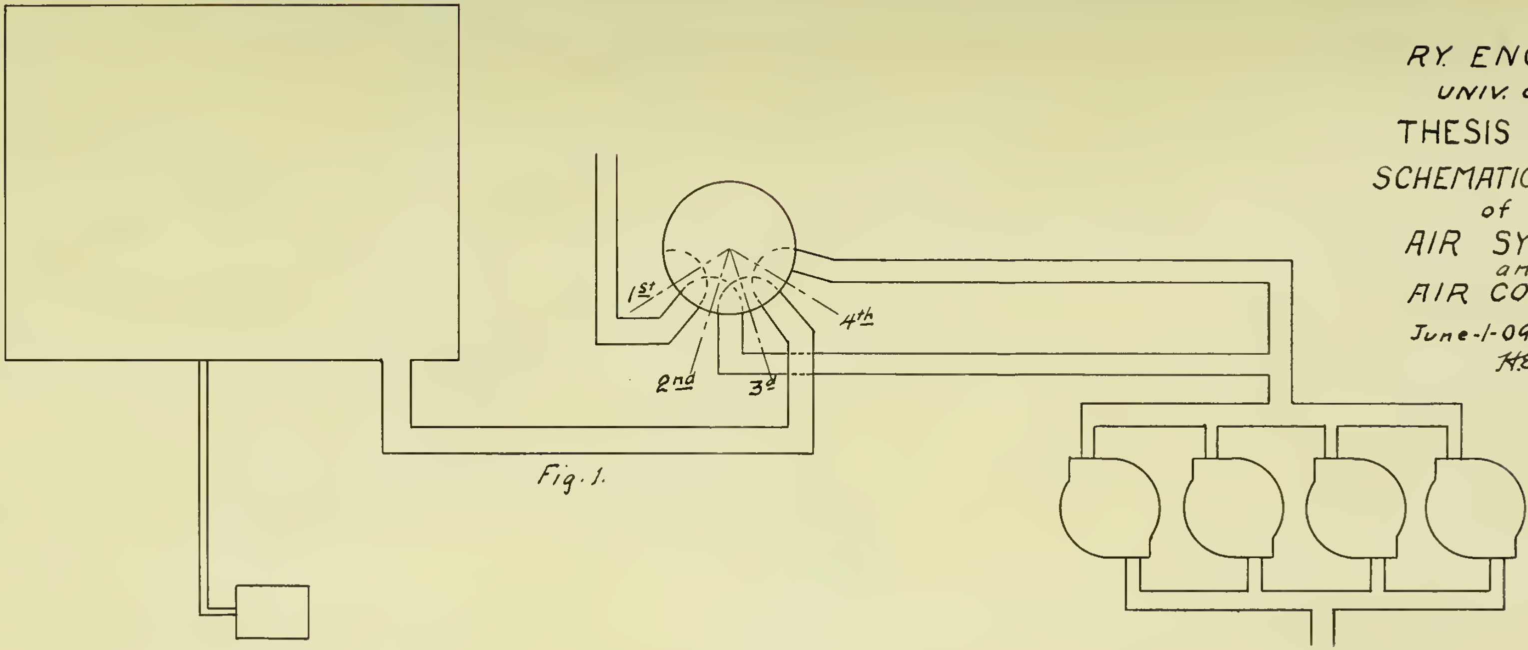

Fig. 1.

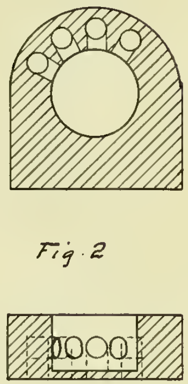

Fig. 2

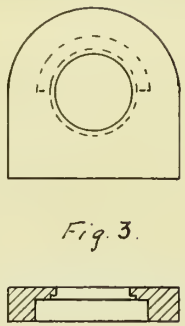

Fig. 3.

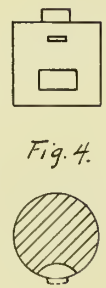

Fig. 4.